

MINERAL TRENDS IN EARLY HESPERIAN LACUSTRINE MUDSTONE AT GALE CRATER, MARS.

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Introduction: The Mars Science Laboratory *Curiosity* rover landed in Gale crater in August 2012 to study the layered sediments of lower Aeolis Mons (i.e., Mount Sharp) [1], which have signatures of phyllosilicates, hydrated sulfates, and iron oxides in orbital visible/near-infrared observations [2]. The observed mineralogy within the stratigraphy, from phyllosilicates in lower units to sulfates in higher units, suggests an evolution in the environments in which these secondary phases formed [2]. *Curiosity* is currently investigating the sedimentary structures, geochemistry, and mineralogy of the Murray formation, the lowest exposed unit of Mount Sharp [3]. The Murray formation is dominated by laminated lacustrine mudstone and is ~200 m thick [3]. *Curiosity* previously investigated lacustrine mudstone early in the mission at Yellowknife Bay [e.g., 4,5], which represents the lowest studied stratigraphic unit. Here, we present the minerals identified in lacustrine mudstone from Yellowknife Bay and the Murray formation. We discuss trends in mineralogy within the stratigraphy and the implications for ancient lacustrine environments, diagenesis, and sediment sources.

Methods: Quantitative mineral abundances were determined by Rietveld refinement of X-ray diffraction patterns returned from the CheMin instrument. CheMin is a transmission X-ray diffractometer/X-ray fluorescence spectrometer located inside the body of the rover [6]. 10 mudstone samples have been drilled and delivered to CheMin thus far. Prior to delivery to CheMin, samples were sieved to <150 μm in CHIMRA [7]. From the base of the stratigraphic section moving up, the 10 samples include: John Klein and Cumberland from Yellowknife Bay (elev. -4520 m), drilled a few meters apart laterally and a few 10s of cm apart vertically; Confidence Hills (-4460 m), Mojave 2 (-4459 m), and Telegraph Peak (-4453 m) from the Pahrump Hills region [8]; Buckskin (-4447 m) from Marias Pass [9]; Oudam (-4435 m) from below the Naukluft Plateau; and Marimba (-4410 m), Quela (-4380 m), and Sebina (-4361 m) near the Murray Buttes. The last eight samples were drilled from the Murray formation. All samples were drilled from lacustrine mudstone, aside from Oudam, which is from a cross-stratified, potentially fluvial interval in the Murray [10].

Minerals in Lacustrine Mudstone: The main phases identified in CheMin patterns of mudstone include feldspar, mafic igneous minerals, iron oxides, crystalline silica, phyllosilicates, sulfate minerals, and X-ray amorphous materials. Although the X-ray amorphous materials show interesting variations in composition within the stratigraphic section [e.g., 8,9], we focus here on the crystalline phases identified in CheMin.

Feldspar and Mafic Igneous Minerals. Plagioclase feldspar is the most abundant crystalline phase in all samples. Minor K-feldspar (sanidine) is present sporadically. Mafic igneous minerals are more abundant near the base of the section (i.e., Yellowknife Bay and the base of the Pahrump Hills), and pyroxene is the most common mafic igneous mineral. We generally model pyroxene as some combination of clino- and orthopyroxene (augite, pigeonite, and ferrosilite). Minor amounts of olivine are intermittently identified.

Iron Oxides. Iron oxide minerals are observed in all samples. Magnetite is the most abundant iron oxide in John Klein and Cumberland from Yellowknife Bay, in Telegraph Peak from the top of the Pahrump Hills, and Buckskin from Marias Pass. Magnetite and hematite are in equal abundances in Confidence Hills, from the base of the Pahrump Hills. Hematite is dominant in Mojave 2 at the base of the Pahrump Hills and is the only iron oxide identified in the last four samples from the Murray (Oudam, Marimba, Quela, and Sebina).

Phyllosilicates. A 10 Å phyllosilicate is observed in all samples, except for Telegraph Peak and Buckskin. A ~13 Å phyllosilicate was discovered in Cumberland in addition to the 10 Å phyllosilicate [5,11]. Phyllosilicate comprises a significant portion (~20+ wt.%) of John Klein, Cumberland, Oudam, Marimba, Quela, and Sebina. The 02 ℓ peaks of the phyllosilicate in John Klein and Cumberland suggest a trioctahedral variety (saponite), whereas the phyllosilicate in the four most recent samples is interpreted as dioctahedral [12].

Crystalline Silica. Significant amounts of crystalline silica are present in Telegraph Peak and Buckskin. Telegraph Peak contains major cristobalite and opal-CT [8], and Buckskin contains major tridymite with minor cristobalite and opal-CT [9]. Oudam contains minor opal-CT. Trace amounts of quartz are identified in all samples drilled from the Murray.

Sulfate Minerals. Sulfate minerals are present in all samples. Ca-sulfates are present in all samples, except for those from the Pahrump Hills. Anhydrite and bassanite are present in Yellowknife Bay, whereas anhydrite and gypsum, often with bassanite, are present in the four most recent samples [13]. Jarosite is a minor component at the base of the Pahrump Hills and is a trace component in Telegraph Peak, Marimba, Quela, and Sebina.

Trends in Mineralogy: There are clear trends in the mineralogy of the mudstone within the stratigraphic section (Figure). Feldspar persists throughout, whereas mafic igneous minerals are more prevalent at the base of the section. The type of iron oxide varies, but magnetite is more abundant in the lower half, and hematite dominates the upper half. Crystalline silica is only common in the middle of the section, whereas phyllosilicate is most common at the base and top of the section. Ca-sulfates are most common in the four most recent samples, and jarosite is most abundant at the base of the Pahrump Hills.

Implications for Ancient Lacustrine Environments in Gale Crater: The observed mineral trends point toward variations in aqueous environments and sediment sources. The prevalence of mafic minerals near the base of the section and the abundance of crystalline silica in the middle suggest the presence of both mafic and silicic source regions for lacustrine sediments [e.g., 8,9]. Saponite likely formed in-situ in Yellowknife Bay from alteration of olivine, suggesting near-neutral pH of early lake waters [11]. The presence of jarosite at the base of the Pahrump Hills and trace amounts in samples near the top of the section indicate the presence of acid-sulfate fluids, but the relatively low abundances of jarosite may suggest acidic alteration was not intense. The abundance of dioctahedral phyllosilicate and hematite at the top of the section and paucity of mafic minerals suggests this part of the section was intensely altered by oxidizing fluids [12]. Diagenesis by basinal fluids in a closed system may explain the mineralogical similarities between Marimba, Quela, and Sebina.

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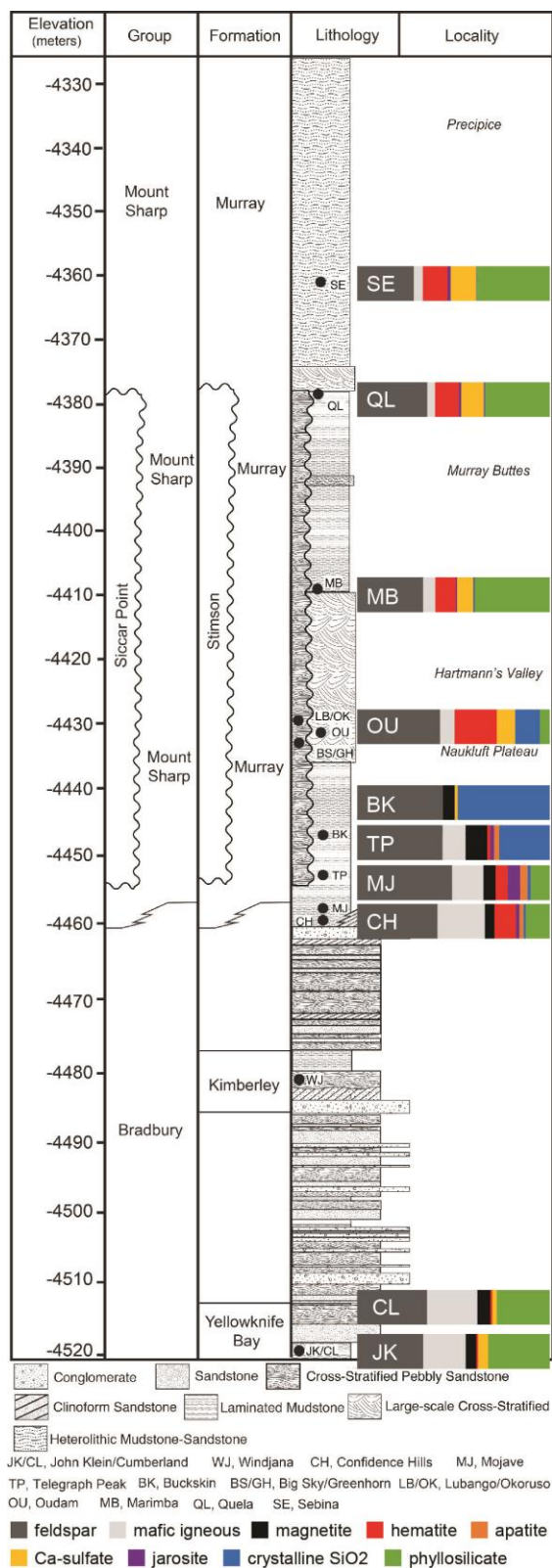


Figure. Stratigraphic column of the *Curiosity* mission to date. Bars showing mineralogy are shown next to each mudstone sample. Abundances have been renormalized to remove the amorphous component.